Mood Expression through Parameterized Functional Behavior of Robots

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***Abstract*— Bodily expression of affect is crucial to human robot interaction. We distinguish between emotion and mood expression, and focus on mood expression. Bodily expression of an emotion is explicit behavior that typically interrupts ongoing functional behavior. Instead, bodily mood expression is integrated with functional behaviors without interrupting them. We propose a parameterized behavior model with specific behavior parameters for bodily mood expression. Robot mood controls pose and motion parameters, while those parameters modulate behavior appearance. We applied the model to two concrete behaviors — waving and pointing — of the NAO robot, and conducted a user study in which participants (N=24) were asked to design the expression of positive, neutral, and negative moods by modulating the parameters of the two behaviors. Results show that participants created different parameter settings corresponding with different moods, and the settings were generally consistent across participants. Various parameter settings were also found to be behavior-invariant. These findings suggest that our model and parameter set are promising for expressing moods in a variety of behaviors.**

I. Introduction

The expression of affect (e.g., emotion and mood) is one of the key social abilities of social robots [1]. Affect can be conveyed outwards through nonverbal expressions like facial expressions, gestures, or postures. Robots' bodily expression of affect is crucial to human robot interaction (HRI), since it enables humans to predict robots' actions by understanding their internal states (e.g., beliefs, intentions, and emotions), and improves the naturalness of HRI and the life-like quality of robots [2]. Bodily expression is also important for robots that lack sophisticated facial features such as NAO, QRIO and ASIMO. Recently, bodily expression of emotions for social robots has been extensively discussed (e.g., [3], [4], [5]). For example, raising both hands shows happiness; arms akimbo shows anger; and covering eyes shows fear. However, these body actions used for expressing emotion rise and dissipate quickly and do not extend over time. For example, robots raise hands for seconds for showing happiness, and then the hands will return to neutral positions. It is unnatural for robots to raise hands for long. Moreover, body actions dedicated to expressing affect may interfere with task-related functional actions. As a result, robots' affects are not visible in between expressions or during a task execution. Our work aims at mood expression, which can indicate robots' affect while performing a task.

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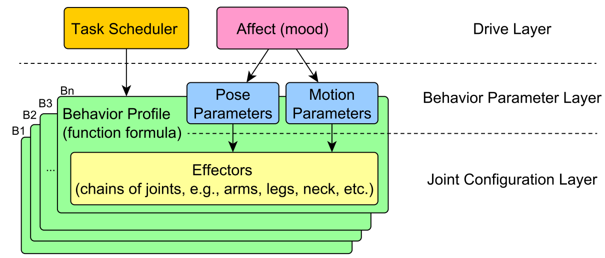


Fig. 1: The multi-layered behavior model

Parkinson proposed that moods may be expressed via bodily postures [6]. Breazeal *et al.* [7] defined *implicit communication*, which convey robots' internal states via behavioral cues. Amaya *et al.* [8] extracted emotional transforms through signal processing and applied them to existing motions to generate emotional animation. Inspired by them, we believe that mood can be expressed through affective cues in robots' behaviors. We propose a layered behavior model (Fig.1) that generates behavior variations through behavior parameter modulation, and the variations provide affective cues. In our model, moods do not trigger behaviors but influence the behavior appearance. Hence, our mood expression does not disorder task scheduling. We applied this model to two concrete behaviors of the NAO robot, and selected behavior parameters related to behavior expressivity (i.e., *how* a behavior is executed) [9]. To clarify whether our model and parameter set are suitable for mood expression and what the parameter values should be for different moods is unclear, we conducted a user study in which participants were asked to create mood expression through our model.

The remainder of the paper is organized as follows. Section II illustrates the challenges of expressing affect during task execution, and reviews the research that motivates our work. Section III describes our behavior model and the implementation into concrete behaviors; Section IV describes the experiment method and procedure. Section V analyzes the experiment data and draws the results; Section VI discusses the remaining challenges and the potential for improving our model; Section VII concludes the main findings of this study.

II. Related Work

Recent research sheds light on the importance of bodily expression of affect for humanoid robots. Although facial expression is one of the main channel of nonverbal expression [2], [3], [4], both [3] and [4] showed that bodily expression improved the recognition rate of robots' emotion. Bodily expression of emotion is typically designed as explicit behavior including static postures and dynamic movements, which are constructed as a whole by "mimicking" those of human beings. For example, body postures were constructed by professional artists [3]; body movements were created according to psychological findings [5]; bodily expressions were collected using motion capture system [10]. Nevertheless, these body postures and movements are difficult to perform while executing a task.

Affect can also be expressed by performing a behavior in different ways, for example, by means of motion interpolation and extrapolation [11], and by behavior parameters. Laban movement analysis (LMA) [12] is a multidisciplinary approach to modeling body movements in general by a broad range of parameters. It has been used in the synthesis of expressive movements for virtual agents [13] and robots [14], [15]. Wallbott [16] studied humans' emotional bodily movements, and annotated behavior patterns as movement "quality" defined by three dimensions. Pelachaud *et al.* [9] characterizes the expressivity of nonverbal behavior using six parameters: spatial, temporal, fluidity, power, overall activation, and repetition. They were applied to an embodied conversational agent Greta, so that Greta can communicate her cognitive and affective states through modulated gestures. All the above research suggests that affect can be reflected by different styles of executing the same type of behavior. With these methods, affect is reflected by the behavior "styles" rather than the behavior "contents" per se. However, effort is still needed to transform these abstract parameters into concrete ones while applying them to particular behaviors. Our goal is to define a set of more specific parameters that can be directly applied to a range of behaviors.

Layered models that link the affect of robots or virtual agents to the behavior parameters have been developed. Yamaguchi *et al.* [17] proposed a model in which (four categorial) emotions can be expressed through modifying three motion parameters (amplitude, speed, and position). They applied the model into single-arm behaviors of the AIBO robot. However, the robot behavior only involved three degrees of freedom (DOFs). Whether this method is effective for a high-DOF platform (e.g., a humanoid robot) remains a question. Lin *et al.* [18] built a hierarchical model to link affects to motion parameters including fluidity, stiffness, speed, power, and spatial extent. With this model, motions of different styles can be generated for virtual agents to express emotions. Our model adopts the layered architecture, and we studied high-DOF behaviors with this model.

Unused body parts can also vary behavior patterns without disturbing task execution. Brooks and Arkin proposed a behavioral overlay model that alters the overall appearance of robots' instrumental behaviors by overlaying them with behaviors of unused body resources [19]. The internal states like attitudes and relationship can be communicated nonverbally through the overlayed behaviors while the instrumental behaviors still function properly. Beck *et al.* [20] investigated the effects of head position on emotion interpretation with an ultimate purpose of establishing an "Affect Space" for bodily expression. Through experiments with static postures, head position was found to have a strong impact on the identification of displayed emotions. We adopt the head movement as a behavior with which task-related behaviors are overlaid.

III. The Design of Mood Expression

A. General Parameterized Behavior Model

This study aims at expressing moods simultaneously with executing functional behaviors. We developed a multi-layer parameterized behavior model. The parameterized behavior model (Fig.1) consists of three layers: 1) a drive layer; 2) a behavior parameter layer; and 3) a joint configuration layer. The drive layer contains the task scheduler and the affect generator. Moods, for instance, can be modeled as dimensional variables in the affect generator, while the task scheduler decides which behavior should be performed. The behavior profile describes behavior functions, while affect determines behavior parameters without breaking the functions, resulting in different behavior patterns. Thus, from the top layer, task scheduler and affect generator can work simultaneously and separately (without interfering with each other).

The behavior parameter layer contains *Pose* Parameters and *Motion* Parameters. These parameters serve as interfaces via which affect can stylize behaviors. To describe the parameters, we employed and modified the synchronization model from [21]. This model describes stroke phases and the time points for synchronization (see Fig.2). Pose parameters focus on effector positions (related to the spatial parameters in [9]). They not only influence positions when an effector is static, but also influence stroke curves when an effector is moving. Start pose, end pose, in-between poses, and stroke curves compose motion trajectories (Fig.2). Motion trajectories specify behavior styles, and it is possible to change motion trajectories without disturbing behavior functions. Pose parameters are closely related to specific behaviors, although their abstract form may be the same. Detailed parameters are introduced in Section III-B. Motion parameters depict the dynamics of a motion. In this study, we investigate four motion parameters: *motion-speed*, *decay-speed*, *hold-time* and *repetition* (see Fig.2). The velocity and hold-time relate to the temporal extent and fluidity in [9].

Joint configuration layer generates a list of joint values for one motion frame (one pose). Joint values need to meet certain constraints placed by behavior functions. However, their values can be modified by behavior parameters within functional bounds. One behavior parameter may influence multiple joints. In our work, the mapping from behavior parameters to joint values is based on numerical functions (for key-points) and interpolations (for in-between points).

B. Implementation of the Model

The behavior model was applied to two behaviors, waving and pointing. In HRI, waving is a frequently used gesture for greeting, saying goodbye and drawing attention, while pointing is a common deictic gesture. These behaviors have only one primary functional effector (the right arm), so the number of the parameters for these behaviors is appropriate for experiments. We selected three pose parameters and four

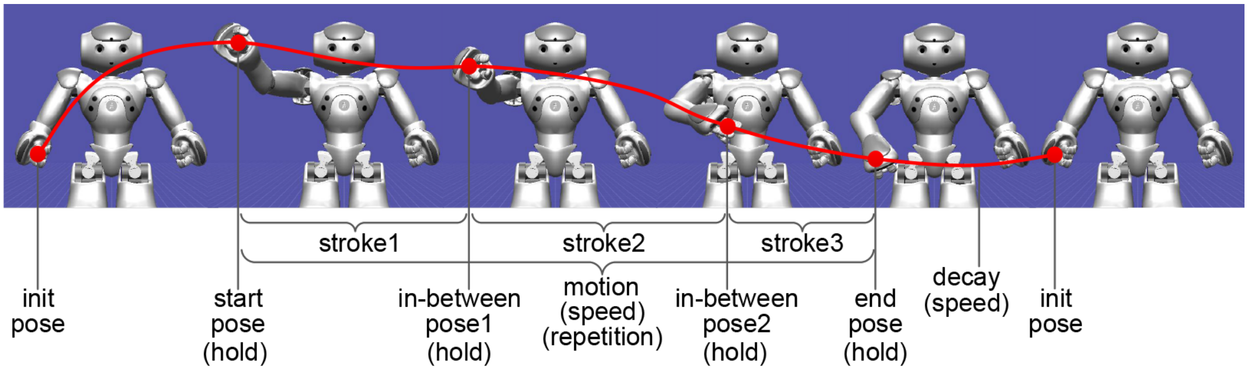
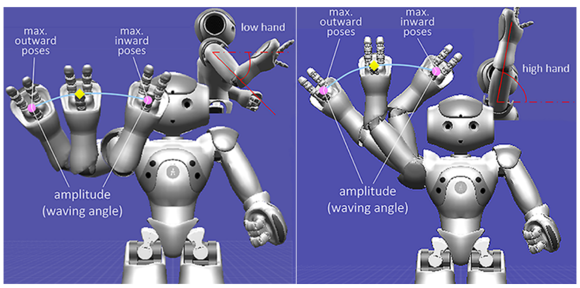


Fig. 2: The pose and motion parameters. The figure is adapted from [21]



(a) waving mode I (b) waving mode II

Fig. 3: The pose parameters of waving behavior

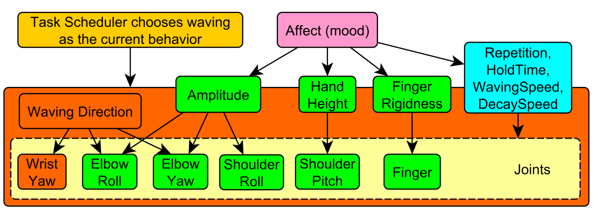


Fig. 4: The parameterizations of waving behavior

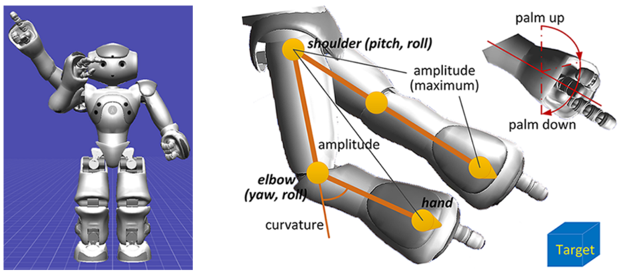
motion parameters for each behavior. Beck *et al.* reports that head movements have a strong effect on expressing affect [20]. Therefore, we added the head to the two behaviors as an effector with two pose parameters, head-up-down (vertical) and head-left-right (horizontal). Thus, each behavior has nine parameters in total. The motion-speed, decay-speed and hold-time for the head movement used the same values as the arm movement, and the head movement is never repeated.

A humanoid robot NAO of academic version 3.3 was used in this study. There are six DOFs in each arm including *Shoulder (Pitch, Roll)*, *Elbow (Yaw, Roll)*, *WristYaw*, and *Fingers*, and two DOFs including *Head (Pitch, Yaw)* in the neck. Although NAO emulates the human body, differences remain in the arm. The wrist-pitch is missing, and the angle range of shoulder-roll and elbow-roll is limited.

1) Waving: We define waving as one hand swinging between two horizontally aligned positions repeatedly, and the palm should always face forward. The concrete parameterized behavior model of waving (Fig.4) embodies the general model (Fig.1). The behavior profile constrains the joints according to the definition of waving, while affective variations can be generated by modifying pose and motion parameters. The two end poses of arm-swings — the maximum inward and outward poses (Fig.3) — are determined by the pose parameters including *a*) *hand-height*, *b*) *finger-rigidness*, and *c*) *amplitude*. Since the palm needs to face forward and NAO's arm does not have wrist-roll joint, the pose of the forearm is fixed. Hence, the *hand-height* can be controlled only by the shoulder-pitch joint, which controls the inclination of the upper-arm (see top-right figures in Fig.3). The waving of a human mainly relies on the movement of elbow joint (the corresponding joint of NAO is elbow-roll). However, it is impossible for NAO to generate a natural waving with enough amplitude merely by the elbow-roll joint, due to its angle range (-2° to 88.5°). In our model, therefore, waving has two general modes that are switched according to the hand-height: arm-swings are realized by controlling elbow-yaw and shoulder-roll joints when hand-height is low (Fig.3a), and by controlling elbow-roll and shoulder-roll joints when hand-height is high (Fig.3b). The *amplitude* specifies the waving angle, and in practice the angle is allocated to the elbow and shoulder. The finger-rigidness controls the straightness of the fingers. Other joints are computed to keep the palm facing forward.

Motion parameters concern the dynamics of the joints. *Waving-speed (motion-speed)* controls the velocity of the arm-swings. *Decay-speed* controls the velocity of the arm returning to the initial pose. The value of the speed is a fraction of the maximum motor speed. *Hold-time* [0.0, 5.0] (seconds) specifies the halting duration when the arm is in the outward or inward poses. It influences the rhythm and fluency of the motion. *Repetition* [1, 10] controls the number of the arm-swing cycles. One cycle is the arm swinging from the outward pose to the inward pose and return to the outward pose. The swing always starts from the outward pose.

2) Pointing: We define pointing as the arm stretching out from the *preparation pose* to the *pointing pose* (Fig.5a). Since NAO's three fingers cannot be controlled separately, we stuck two of them to the hand allowing only one finger to move as index finger. The concrete parameterized behavior model of pointing (Fig.6) embodies the general model (Fig.1). The behavior profile constrains the joints according to the definition of pointing, while affective variations can be generated by modifying pose and motion parameters. The pointing pose is determined by pose parameters including *a*) palm-up-down, *b*) amplitude, and *c*) finger-rigidness.



(a) preparation & pointing (b) pose parameters

Fig. 5: The pose parameters of pointing behavior

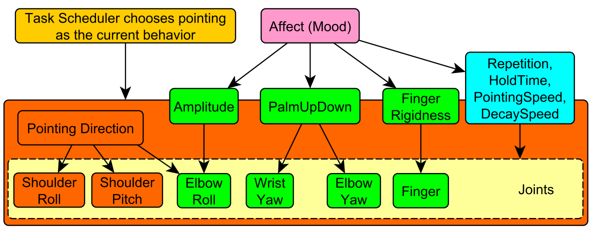


Fig. 6: The parameterizations of pointing behavior

Palm-up-down controls the palm direction of the pointing pose (see the top-right of Fig.5b). The palm direction is controlled by the wrist-yaw and elbow-yaw joints, whose values are computed according to the normal vector to the palm. *Amplitude* is defined as the outstretching extent of the arm. It is controlled by the curvature of the elbow. Fig.5b illustrates the amplitude and its maximum state. *Finger-rigidness* is the straightness of the index finger. The finger cannot be fully bent to avoid the deviation of the pointing direction. The values of other joints are computed according to the pointing direction. NAO has only one DOF (WristYaw) in the wrist, and NAO's fingers can only be straight or bent, so the pointing direction is almost in line with the direction of the forearm (see Fig.5b). In the experiment, the pointing direction is fixed to the right-up of the robot (Fig.5a).

Regarding motion parameters, *pointing-speed (motion-speed)* refers to the velocity of the arm moving from the preparation pose to the pointing pose. *Decay-speed* refers to the velocity of the arm returning to the initial pose from the pointing pose. *Hold-time* [0.0, 5.0] (seconds) refers to the time that the pointing pose persists before decaying. *Repetition* [0, 5] refers to the frequency of the arm returning to an *intermediate pose* and moving to the pointing pose again after the first pointing pose. Each joint of the intermediate pose (J_{int}) is interpolated between the preparation pose (J_{pre}) and the pointing pose (J_{pnt}):

$$J_{int} = J_{pre} + \alpha \times (J_{pnt} - J_{pre}) \quad (1)$$

α is a percentage set to 0.5.

IV. Experiments

A. Research Questions and the Initial Design

This study aims at designing mood expression superimposed on behaviors of a humanoid robot. A parameterized behavior model has been developed so that moods can be expressed through behavior variations. We applied the model to two functional behavior prototypes (waving and pointing),

TABLE I: The principles of the initial design

Parameters		Waving		Pointing	
		Positive	Negative	Positive	Negative
Motion	MotionSpeed	fast*	slow*	fast*	slow*
	DecaySpeed	fast*	slow*	fast*	slow*
	HoldTime	short	long	long	short
	Repetition	high*	low*	high*	low*
Pose	HandHeight	high	low	/	/
	PalmUpDown	/	/	up	down
	FingerRig.	straight*	bent*	straight*	bent*
	Amplitude	large*	small*	large*	small*
	HeadVer.	up*	down*	up*	down*
	HeadHor.	look at you	look away	look at you/target	look away

* general principles

for which the pose and motion parameters can be set and assessed. The research questions are

Q1) Can our model and behavior parameter set be used for expressing mood?

Q2) What values should those parameters have?

To answer the questions, we created initial settings for both behaviors for the positive and negative moods. Then we conducted an experiment to test whether people are able to use the parameters in our model to generate different affective robot behaviors corresponding with different moods, and whether their deign principles are consistent with ours for the initial design. Based on literature (e.g., [16], [20], [22]) and our experience, we formulated our design principles summarized as follows and outlined in Table I.

- *Hand-height* A higher hand pose presents a more positive mood. When waving is in mode II (Fig.3b), the whole-arm activation shows more positive moods.
- *Palm-up-down* Palm facing up shows openness for positive moods while facing down shows defensiveness for negative moods.
- *Finger-rigidness* Bent fingers generally show reluctance or unconcern reflecting a negative mood; straight fingers show seriousness reflecting a positive mood.
- *Amplitude* A large waving angle represents expansiveness indicating a positive mood; a small waving angle represents narrowness indicating a negative mood. For pointing, an outstretched arm increases the hand traveling distance and the arm rigidness, indicating a positive mood; an unextended arm shows unconcern or reluctance indicating a negative mood.
- *Motion-speed* Fast motion speed expresses positive moods (e.g., happiness and excitement); slow motion speed expresses negative moods (e.g., sadness).
- *Decay-speed* Fast decay speed expresses elation or excitement; slow decay speed expresses fatigue or sadness.
- *Hold-time* Short hold time makes body movements fluent and smooth, indicating elation or delight; long hold-time makes body movements jerky or sluggish, indicating sadness or depression. We used this principle for waving, whereas for pointing we used long hold-time to show emphasis or willingness (to show directions) for positive moods, and short hold-time for negative moods. Particularly, zero hold time will cause the pointing pose to decay immediately. The resulting non-persistence shows unconcern, fatigue, and reluctance.
- *Repetition* Repeated movement shows excitement or elation. Non-repeated movement stands for neutral or

even negative moods like boredom, fatigue, or depression. For pointing, repetition also shows emphasis.

- *Head-up-down* Raised head indicates a positive mood while lowered head indicates a negative mood.
- *Head-left-right* Generally, head turning away from users (to avoid eye-contact) indicates a negative mood, while facing users indicates a positive mood. In addition, to indicate a negative mood through pointing the head should turn away from both users and the pointing direction, while to indicate a positive mood the head can face either users or the pointing direction.

According to the above principles, we created parameter settings across mood levels (the initial settings) using a user interface which was used in the experiment.

B. Design

1) User Design Experiment: The objective is to embed affective cues of different moods in waving and pointing by modulating behavior parameters. The parameters can be adjusted using sliders or numeric boxes on a user interface. Participants can click a “play” button to display the adjusted behavior on the real NAO robot, so that they were able to observe the behaviors from different positions and view-angles. Thus, they can test the effect on the behaviors caused by the changes they made intuitively. The goal is to design behaviors that display the mood that the robot is supposed to have. In this study, the mood is represented only by *valence* with five levels ranging from negative to positive: *very unhappy*, *unhappy*, *neutral*, *happy*, and *very happy*. The experiment is a within-subject design. Each participant needed to set values for the nine behavior parameters for each behavior and mood condition. The behavior parameters were reset to neutral values each time a participant started designing for another valence level. The order of the behavior and mood conditions was counter-balanced: *a*) Pointing → Waving, Negative → Positive; *b*) Pointing → Waving, Positive → Negative; *c*) Waving → Pointing, Negative → Positive; *d*) Waving → Pointing, Positive → Negative.

2) Comparison Experiment: In the design experiment, participants may fail to find the parameter settings they would have preferred most due to the complexity of the parameter space and the limited time. It is easier to identify a preferred design by comparison. Hence, after the design experiment, participants were asked to compare their own design and the initial design. They were not informed about who created either of these two designs. They were asked to choose the one they preferred and provide reasons.

C. Participants

Participants were recruited by advertisements. 24 university students (14 males, 10 females) with an average age of 23 (SD=4) participated in this experiment. They were all studying industrial design, and all had some experience of design. A pre-experiment questionnaire confirmed that none of the participants had any expertise related to this study per se. Each participant received a ten-euro coupon as a compensation for their time.

D. Procedure

During the experiment, participants sat at a desk to manipulate the robot through a user interface. The chair position was fixed by aligning the chair arms with two markers on the desk. The robot stood on the desk and its location was fixed by markers underneath. Thus, the relative position between the participant and the robot was fixed to minimize the bias on participants' perception of the robot head direction. A NAO robot of grey-white color was used to minimize the impact of color on participants' perception of moods.

After signing a consent form and filling in a pre-experiment questionnaire, each participant received an explanation of the tasks for both experiments. Before the actual experiment, participants were asked to familiarize themselves with the behavior parameters during a trial session and they can ask the experimenter to clarify anything unclear. Then the actual user design experiment began. Participants were asked to adjust the parameters and test the behavior on the robot. For each behavior participants can proceed to the next mood by clicking a “next” button if they are satisfied with their design for the current mood. They were allowed to modify saved parameters of previous moods by clicking a “previous” button. However, after they proceeded to the second behavior, they were not able to modify the first one. The comparison experiment started after participants completed the user design experiment. For each behavior and mood, participants were asked to display two parameter settings on the robot by clicking buttons on the user interface. They were asked to select the one they preferred most and provide reasons. The mood levels for each behavior were presented in a random order, and the order of behaviors were counter-balanced. After finishing the experiment, participants filled in a post-experiment questionnaire and were informed about the purpose of the study. On average, the experiment took 90 minutes per participant.

V. Analysis and Results

A. Correlation between Valence and Behavior Parameters

This section investigates in detail the correlation between valence and the nine behavior parameters of our model. Valence is the independent variable (within-subjects factor), and the nine parameters are the dependent variables. We used one-way repeated-measures *Analysis of Variance (ANOVA)* to analyze the user settings to test whether significant difference of each parameter exists between valence levels. Table II shows the results and effect size η^2. Results show that for both behaviors almost all parameters vary significantly with mood. For the hold-time of waving, the difference is approaching significance level. Therefore, it indicates that for both behaviors participants can create parameter settings corresponding with different moods.

The results of pairwise t-tests with Bonferroni correction are provided in Fig.7 and Fig.8 for the parameters that have significant difference between valence levels. The parameter means are annotated on the bars. For waving, the values of

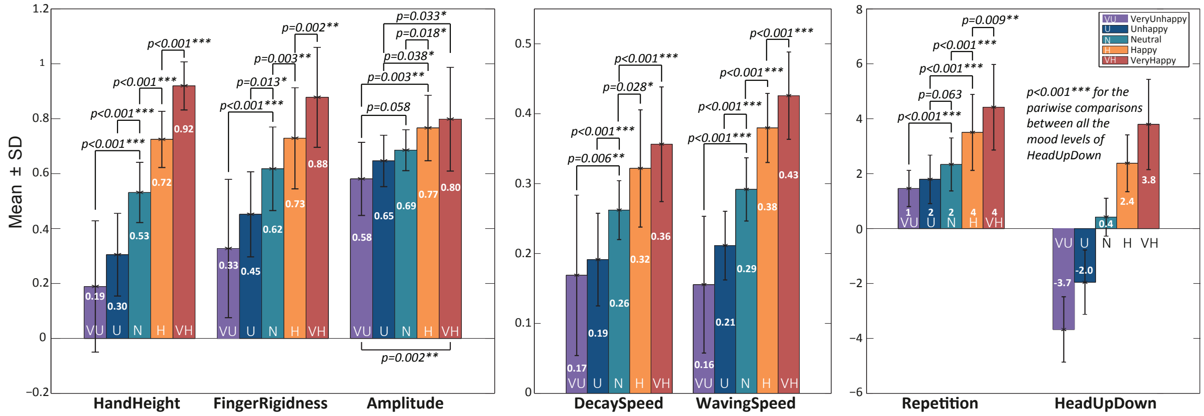


Fig. 7: pairwise comparison between valence levels of waving behavior parameters

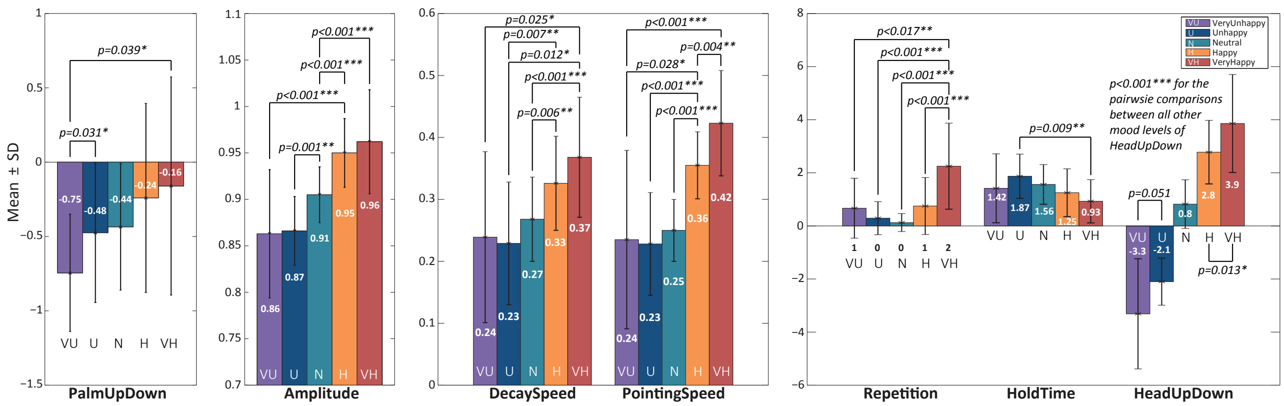


Fig. 8: pairwise comparison between valence levels of pointing behavior parameters

TABLE II: Results of repeated-measures ANOVA

Waving				Pointing			
Parameters	**F(4,20)**	**Sig.**	η^2	**Parameters**	**F(4,20)**	**Sig.**	η^2
HandHeight	105.79	***	0.955	PalmUpDown	3.36	*	0.402
FingerRig.	17.82	***	0.781	FingerRig.	1.80	0.168	0.265
Amplitude	5.31	**	0.515	Amplitude	22.47	***	0.818
Repetition	22.01	***	0.815	Repetition	13.67	***	0.732
HoldTime	2.66	0.063	0.348	HoldTime	3.53	*	0.414
DecaySpd	16.75	***	0.770	DecaySpd	6.84	**	0.578
WavingSpd	42.39	***	0.894	PointingSpd	37.31	***	0.882
HeadVer.	75.58	***	0.938	HeadVer.	42.55	***	0.895
HeadHor.	1.39	0.274	0.217	HeadHor.	0.70	0.602	0.123

∗ p<0.05, ∗∗ p<0.01, ∗ ∗ ∗ p<0.001

hand-height, finger-rigidness, amplitude, repetition, decay-speed, waving-speed, and head-up-down increase with increasingly positive valence. Participants selected the hand-height value of waving mode I for happy and mode II for very-happy (see Fig.3). As a result, we conclude that waving mode II displays more happiness than mode I. For pointing, the values of palm-up-down, amplitude, decay-speed, pointing-speed, and head-up-down increase with increasingly positive valence. Overall, for these parameters the user design is consistent with the initial design (see Tab.I), except for the repetition of the pointing, which does not increase with increasingly positive valence (see Fig.8).

B. Patterns of Parameters

By connecting the points in the scatter plots of the parameter means, we obtain global patterns (Fig.9) for the initial (blue) and the user (red) settings. The mean of each parameter is scaled using the formula:

$$P_{scaled} = \frac{P_{orig} - P_{grandmin(n,m)}}{P_{grandmax(n,m)} - P_{grandmin(n,m)}} \quad (2)$$

n is the number of participants. m is the number of moods. The grandmin/grandmax is the minimum/maximum value of the parameter among the total n×m samples of the user settings. The patterns reveal the interrelations between parameters for each behavior and mood condition. Although exact parameter values may differ between behaviors, similar patterns are found in both behaviors for the same mood level (see Fig.9). The patterns of negative moods are similar for the two behaviors: the values of finger-rigidness, amplitude, decay-speed and motion-speed are moderate; the repetition is low; the head is lowered. The patterns of positive moods are similar: the values of finger-rigidness, amplitude, decay-speed and motion-speed are large; the repetition is high; the head is raised.

C. Differences from the Initial Design

Although the user design is overall consistent with the initial design, differences of exact parameter values exist between them. Participants provided reasons in the comparison experiment. Participants' choices are shown at the top of each figure in Fig.9. Binomial tests suggest participants' choice is not random for neutral (*p<0.005*) and happy (*p=0.064*) pointing. One reason provided by participants is

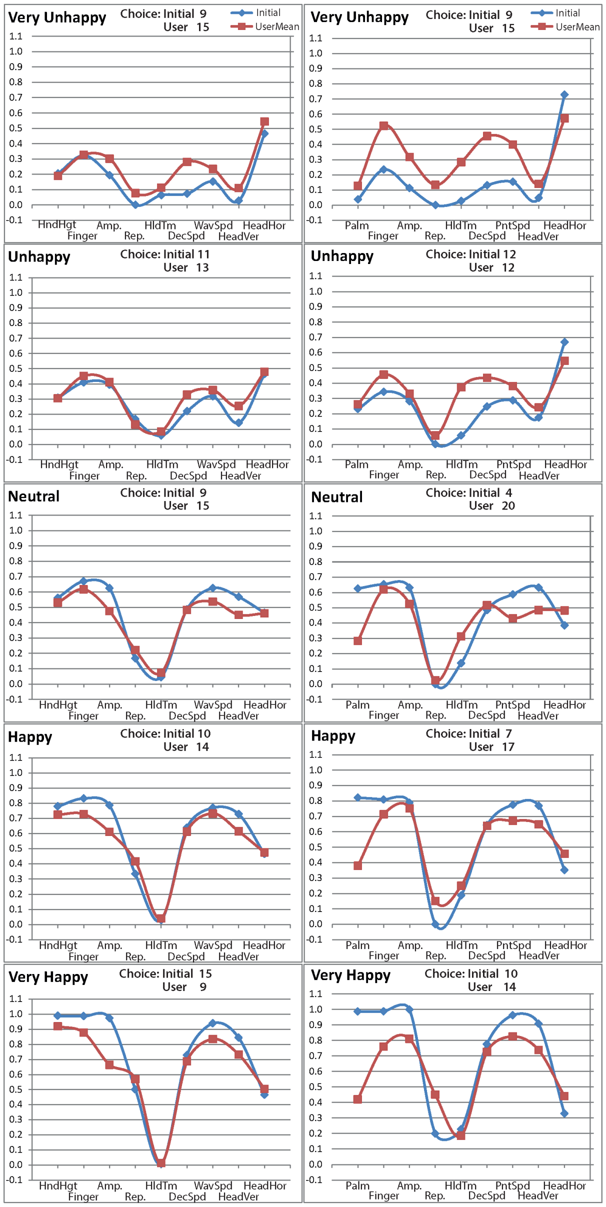


Fig. 9: The patterns of the means for the initial and user designs. left column: waving; right column: pointing.

that they judged that the initial design was more positive than it should be. Another reason is that participants thought palm facing up looked unnatural. This also occurs for very-happy pointing (see Fig.9). Participants selected a different value for palm direction than the initial design for neutral (*t=-7.88, p<0.001*) and positive moods (happy: *t=-6.78, p<0.001*; very-happy: *t=-7.68, p<0.001*). Although more participants turned the palm up for positive moods, still over 60% participants did not turn the palm up. Five participants explicitly mentioned in the comparison experiment that the palm should be down, and some of them thought palm facing up looked weird. It seems that the usual function of palm up to display openness does not apply in the case of pointing.

We also discuss some of the salient differences between the initial and user designs that are apparent from Fig.9. One-sample t tests were used to identify the differences. For the very-unhappy waving, although participants set decay and waving speed slow, they are not as slow as the initial design (decay-speed, *t=4.21, p<0.001*; waving-speed, *t=1.78, p=0.089*). These participants considered the robot to be “sad” or “dejected”. Interestingly, some participants set the speeds very fast because they considered the robot to be “angry” or “mad”. Similarly, participants set faster speeds for the negative pointing than the initial design (very-unhappy: decay-speed, *t=5.65, p<0.001*; pointing-speed, *t=3.59, p<0.005*; unhappy: decay-speed, *t=4.40, p<0.001*; pointing-speed, *t=2.20, p<0.05*;). About 25% participants set the speeds very fast for the negative pointing because they considered the robot to be “mad”, “annoyed”, “aggressive”, or “impatient”. These settings often have short hold-time and multiple repetition as well. Interestingly, one participant seems to have intended to create a pointing with staring by making the head face down, pointing-speed very fast (max), decay-speed very slow (min), and hold-time very long (max). Although participants set larger amplitude for neutral and positive waving, they did not set as large as the initial design (neutral: *t=-6.20, p<0.001*; happy: *t=-4.26, p<0.001*; very-happy: *t=-4.71, p<0.001*). They mentioned that the initial design made the motion more rigid and unnatural. Five participants set the amplitude small for the positive waving, because the small amplitude with fast speed caused whole-body shaking of the robot, which was perceived as happy or excited. For the negative pointing, participants considered the finger may influence the pointing direction, so they did not set the finger as bent as the initial design (very-unhappy: *t=3.79, p<0.001*; unhappy: *t=2.07, p<0.05*).

D. Behavior-Invariant Parameters

Participants created different settings between the two behaviors for some parameters of the same type, because these parameters have different functions for the behaviors. Whereas most participants set the hold time for waving within one second, they set it much longer for pointing. Possible reasons can be that hold time influences the fluency of waving, but in the case of pointing it indicates the emphasis on the target. The head-left-right parameter is related to eye-contact for both behaviors, but for pointing it also emphasizes the pointing direction. Most participants turned the robot head sideways for both behaviors of a very-unhappy mood. For neutral and positive moods, almost all participants made the robot head face themselves for waving, but for pointing almost all participants made the robot head face either themselves or the pointing direction. Finally, numerous repetition seems more natural for waving than for pointing, and bent finger may influence the function of pointing. Whereas these parameters are found to vary with behaviors, we also found parameters that are in essence behavior invariant. As mentioned in Section V-A, the same trends can be found in amplitude, decay-speed, motion-speed, and head-up-down for both behaviors. Moreover, the patterns of finger-rigidness, amplitude, decay-speed, motion-speed, repetition and head-up-down are similar between behaviors for positive and negative moods. Therefore, we believe it will be possible to generalize our findings to mood-modulation of other behaviors.

VI. Discussion

Behaviors are parameterized in this study, and we intended to address the effect of individual parameters on users' perception of mood in the behaviors. However, participants' perception is usually an overall assessment of the behavior as a whole instead of assessments of individual parameters. Moreover, parameters are probably interdependent. One parameter may cause different effect on users' perception when other parameters changed. Thus, more careful experiment control is needed to address the individual effect and interdependency of the parameters.

Although we only investigated the valence dimension in this study, some parameters may relate more to the arousal dimension (active vs. passive moods). For example, the participants that set the speeds fast considered the robot was angry (high arousal), while the ones that set the speeds slow considered the robot was sad (low arousal). We will add the arousal dimension to our model and study the correlation between behavior parameters and this dimension.

Experiment shows that creating settings for pointing seems more difficult than waving. It implies that the expressivity of behaviors per se may differ from each other, i.e., modulating parameters of the same type may produce different quantity of affective cues for different behaviors. The effect sizes of ANOVAs indicate that the strength of the association between valence and each behavior parameter may be different (see Table II). With quantitative assessment of affective cues provided by each parameter, a robot system can select parameters for expressing mood quantitatively. Combined the quantitative assessment with a further study of generic (behavior-invariant) parameters, a minimum parameter set can be found for each behavior.

For each behavior and mood condition, we created weighted settings that integrate the findings from the user study and our design principles (see Section IV-A). The video clips of the initial and weighted design can be found on our website[1]. An evaluation of the generated mood expression in which participants recognize mood from behaviors will be done in the future. Numerical functions that correlate valence with each parameter can be established using the weighted settings and interpolation. These functions can be evaluated through experiments and improved by tuning the interpolated points.

VII. Conclusion

This study indicates that with our model affect can be expressed through ongoing behavior of robots during a task. In our model, affect (mood in our particular case) is expressed through affective cues provided by behavior variations, and the variations are generated by behavior parameter modulation. Experimental results show that our model and parameter set are able to generate such behavior variations. Our model contains specific parameters that can be directly used for modifying robot behaviors. Moreover, various parameters were found to have identical function of expressing moods for the two behaviors. This suggests that some of our parameters can be used as generic ones in a variety of behaviors, and the design principles of these parameters can also be applicable to other behaviors. The contribution of this study is to enrich the affective expression of social robots by enabling them to express affect through body language during task execution.

[1] http://ii.tudelft.nl/~junchao/moodexpression.html

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